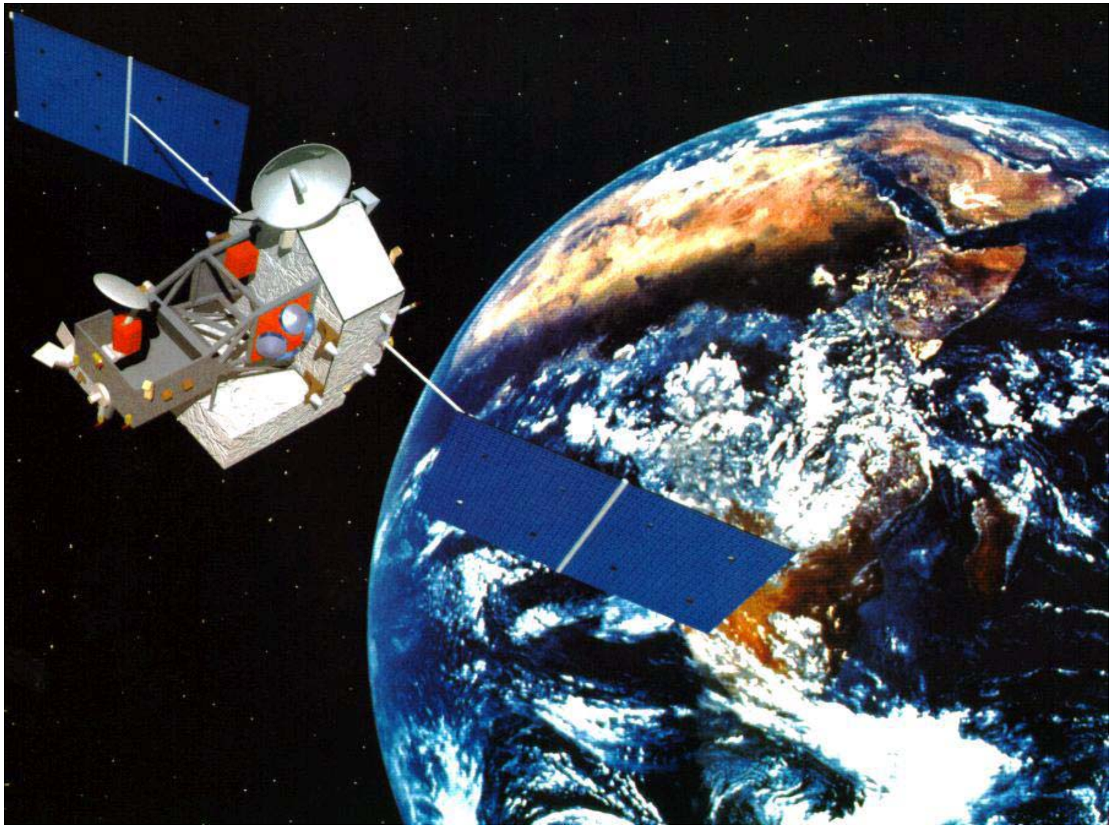
TRMM Controlled Re-Entry Plan Review

NASA/Goddard Space Flight Center

January 29, 2003



Introduction

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Purpose Of This Review

- To review the Controlled Re-Entry Design and Plan for TRMM prior to the start of the test and simulation phase with a goal of getting to a Mission Operations Readiness Review by the end of FY03.
- RFAs that result from this review will be incorporated into the draft “TRMM Controlled Re-Entry Plan” in the appendix of your package and the plan will be submitted for review and approval by Center Level Management and NASA HQ Code Y.
- Once approved, the plan will be baselined and put under ESMO Project Configuration Management.
- The purpose of this review is not to debate whether we should or should not do a controlled re-entry; however, key milestones are provided for decision making.

Agenda

Introductory Remarks Earth Science Mission Operations (ESMO) Project Manager	8:00-8:05	Paul Ondrus
Introductory Remarks Review Team Chair	8:05-8:10	Dennis Dillman
Introduction	8:10-8:50	Vickie Moran
Final Re-Entry Survivability (Orsat) Analysis Results	8:50-9:10	Josephine San
Science Issues With Controlled Re-Entry	9:10-9:30	Dr. Robert Adler
TRMM Re-Entry Team, Programmatics, and Triggers	9:30-9:50	Vickie Moran
Guidance, Navigation, and Control (GN&C) Subsystem	9:50-10:00	Sam Placanica
Reaction Control Subsystem (RCS)	10:00-10:20	Scott Glubke
Thermal Subsystem Issues For Re-Entry	10:20-10:30	Walt Ancarrow
RF Communications Subsystem	10:30-10:40	John Zuby
Re-Entry Design & Contingencies	10:40-12:30	Josephine San
Lunch	12:30-1:30	
Re-Entry Trajectory Design & Contingencies	1:30-2:00	Frank Vaughn
Flight Software Support Plan	2:00-2:20	Bob Strang
Flight Operations Plan	2:20-2:40	Justin Knavel
Simulation Plan	2:40-3:00	Clay Deyarmin
Flight Dynamics Facility (FDF) Interfaces and Support Plan	3:00-3:20	Steve Slojkowski
Network Support Plan	3:20-3:30	John Ervin
Other Supporting Elements Of Plan	3:30-3:40	Vickie Moran
Future Work and Topics To Be Discussed At Mission Operations Readiness Review (MORR)	3:40-4:00	Vickie Moran
Summary	4:00-4:10	Vickie Moran
Wrap-Up & Summary	4:10-4:30	Dennis Dillman

Summary of April 2001 Review

- Reviewed NASA HQ policy towards spacecraft re-entry as it relates to TRMM.
- Familiarized the Review Team with the TRMM design and its issues with respect to re-entry.
- Obtained an independent assessment of the other options being considered for TRMM.
- Outcome of that review…
  - TRMM was boosted from 350km operational orbit to 402.5 km operational orbit in August 2001 to extend mission life.
    - » Had this change not been made, TRMM would have hit the fuel trigger for reentry in August 2002.
  - Narrowed the options presently being considered for re-entry of TRMM to:
    - » Uncontrolled—expend all the fuel for science; TRMM performs station-keeping maneuvers to maintain 402.5km until ~ May 2010-Aug. 2011 and re-enters due to natural decay of orbit 211-347 days later.
    - » Controlled—maintain adequate fuel budget (134kg) to target TRMM's re-entry to a specific footprint in the Pacific Ocean.

15 Requests For Action

- RFA #1—ORSAT Model
  - Describe how sensitive the model is to changes in parameters which are chosen by human judgement (e.g. how sensitive is the result of the model to selection of an oxidative heating efficiency factor of 0.5?)
  - Validate analysis using data from an actual spacecraft that has reentered such as CGRO or other NASA or DoD spacecraft.
- Response—Recommend Closure
  - JSC delivered the final report for the TRMM—Spacecraft Survivability Analysis in September 2002. This analysis was very detailed modeling over 200 specified components (91%) of TRMM. The result of the analysis was that 7 component types survive producing a debris casualty area of 11.3m^2. This debris casualty area was the result of a parametric assessment for borderline components on the verge of either surviving or demising.
    - » This is the 3rd ORSAT analysis that was performed for TRMM each one increasing in number of components modeled and fidelity. The first two yielded casualty areas of 13.8m^2 and 12.3m^2. The variation in the final results has not been large.
    - » Several of the TRMM borderline objects were evaluated by varying the initial temperature, the oxidation efficiency of the material, and the wall emissivity. This resulted in a best case of 10.2m^2 to a worst case of 15.3m^2 with a best estimate of 11.3m^2.
  - A classified meeting was conducted at JSC at which JSC received data on the CGRO re-entry. Validation of the model is described in the ORSAT Tutorial and is ongoing. The TRMM analysis was performed with the most current version of ORSAT (ver. 5.5) available at the time.
  - We concur the results of this analysis.

15 Requests For Action

- RFA #2—Raising TRMM's Orbit
  - Press for quick resolution of the effect on science data of increasing the orbit to 400km. Once this information is on the table, make the decision ASAP.
  - If 400km is not acceptable from a science standpoint, determine maximum acceptable altitude from a science standpoint and evaluate the orbit lifetime benefits of that altitude.
- Response—Closed
  - TRMM's orbit was boosted from 350km to 402.5km in August, 2001.
- RFA #3—Non-Targeted Re-Entry Option
  - Drop the non-targeted re-entry option. Focus time and resources on the targeted and maximum lifetime uncontrolled re-entry options.
- Response—Closed
  - The non-targeted re-entry option was immediately dropped.

15 Requests For Action

- RFA #4—Contingency Mode
  - Investigate whether the contingency mode shortens time for sun acquisition, earth acquisition, and yaw acquisition. Contingency mode may also be useful if 400km circular orbit is attempted.
- Response—Closed
  - The ACS switched to contingency mode during the orbit boost from 350km to 402.5km. The Earth sensor failed above 380km.
  - Contingency mode is baselined for attitude control during the re-entry burns. Simulations show the time required for mode transitions is adequate.
- RFA #5—Assumption of velocity pointing for delta-V maneuvers.
  - Account for maneuver inefficiency during long burns in a non-circular orbit using Earth-pointing mode, not velocity pointing mode.
- Response—Closed
  - All maneuvers in the current analysis/plan account for maneuver inefficiency due to Earth-pointing attitude.

15 Requests For Action

- RFA #6—Stuck solar array.
  - Investigate what heroic load shedding, including survival heaters, is possible in an end-of-life scenario, including survival in safemode, for a solar array stuck at any angle. Stuck solar array may not require immediate re-entry.
- Response—Recommend closure.
  - The –Y wing was predicted to stick shortly after launch because the –Y SADA temperature was higher than expected on orbit.
  - The –Y wing did stick subsequent to the review on Sept. 4, 2002.
  - The –Y wing has been permanently stowed at 0º (minimum drag position) by opening the GSACE motor windings.
  - In sun acquisition and safe mode, there is adequate power from the +Y wing only to power the spacecraft with all instruments off. No further load shedding is required.
    - » To provide additional power margin in sun acquisition and safe mode the spacecraft will be pitched 15º to provide some sun on the –Y wing.
  - The +Y wing is not likely to stick. The total output rotation for the +Y wing was slightly more than 7 million degrees as of October 4, 2002. The life test unit rotated through a total of approximately 11 million degrees and appeared internally and externally to be in good working order at the end of the test. The +Y SADA has a more benign environment than the life test unit, in that its temperature has always been 9-16C whereas the life test unit was cycled between 5-37C. The +Y SADA will reach the life test travel in March 2006.
  - Contingency plan is provided for +Y wing sticking in subsequent chart.
  - The following components are not automatically load shed but could be load shed if necessary to save power: PSIB A, ACE A (ACE B is required due to the –Y SA wing stowage as CSS Set B will be used in Safe Hold), 1 Gyro

15 Requests For Action

- RFA #7—Re-servicing Option
  - Investigate using a Spartan to grapple TRMM and use its own fuel to produce a controlled re-entry. This could allow TRMM to use all of its onboard fuel to extend the baseline mission.
- Response—Recommend closure.
  - A very preliminary study was conducted by Mark Steiner, Dr. Landis Markley, Josephine San, Dave Olney, and Vickie Moran. A summary was sent to NASA HQ TRMM Program Executive November 5, 2002 for review.
    - » Conclusion--technical challenges, redesign efforts for current Spartan, requires Shuttle launch, at least 3 years to implement and a minimum of $30-$40 million

15 Requests For Action

- RFA #8—Thermal
  - If possible, design the trajectory so that perigee occurs during orbit night to minimize overheating concerns.
- Response—Recommend closure.
  - Thermal analysis shows that required components stay within acceptable limits at 150km perigee with full sun. Although this does not appear to be a required thermal constraint, at this time, there may be other future requirements for perigee to be constrained to orbit night. If this does become a constraint, it does not impact the current re-entry plan. There is approximately an 8-10 day window every 34-36 days (5 weeks) when apogee occurs during the day. Constraining burn 1 to this window will constrain the final perigee to orbit night.

15 Requests For Action

- RFA #9—Programmatics
  - For CGRO re-entry the center management wanted to have a team in-place (ready to deploy) in a contingency scenario where the debris falls over land mass. This team was required to quickly visit that area to document/evaluate damage claims.
- Response—Recommend closure.
  - The TRMM Controlled Re-Entry Plan calls for a team to be assembled that would be ready to travel to the re-entry site if the TRMM controlled re-entry fails and TRMM debris falls over land. The team will consist of legal council, 2 technical engineers familiar with TRMM hardware, and a photographer.

15 Requests For Action

- RFA #10—General
  - Address collision avoidance in the plan. Develop a plan that will address how you will determine which assets need to be avoided in-orbit, what the conjunction criteria will be, and how such issues will be resolved if they occur.
  - Response—Recommend Closure
    - » Collision Avoidance Plan—The TRMM Controlled Re-Entry Plan requires the development of a Collision Avoidance Plan prior to the Mission Operations Readiness Review (MORR).
  - Prediction of tank explosion. There was a long debate on whether the fuel tank will explode or not during re-entry, and what that means for debris footprint. Don’t get sucked into this debate, since nobody can predict what happens. Show that you have enough conservatism in the footprint determination to envelope a fuel tank explosion.
  - Response—Recommend Closure
    - » The tanks are predicted to survive according to JSC’s ORSAT analysis. There is evidence that CGRO’s tanks did explode and CGRO was within its footprint. We are using the same process to envelope the footprint that CGRO did. The footprint analysis assumes a ballistic coefficient of nominal intact spacecraft of 2.5-177.5kg/m^2 and breakup at 84km.

15 Requests For Action

- RFA #10—General
  - Solar flare during re-entry: Show that your attitude control system can handle any increase in atmospheric density due to a last minute solar flare.
  - Response—Open
- RFA #11—Ground System
  - The spacecraft simulator was a very valuable tool for the CGRO re-entry mission: 1) training and simulations, and 2) procedure development and verification, etc. Evaluate the fidelity of the TRMM simulator for these purposes.
  - Response—Recommend Closure
    - » The fidelity of the TRMM spacecraft simulator to adequately simulate the controlled re-entry has been assessed. A number of modifications/updates to the Hybrid Dynamics Simulator (HDS) models have been identified. They are included in the Flight Software section.

15 Requests For Action

- RFA #11—Ground System
  - Make sure there is enough depth in ground system resources (hardware, flight ops team, etc.) to allow continued science mission while the re-entry team is preparing and training for the mission.
  - Response—Recommend Closure
    - » TRMM has adequate ground system resources to support real-time operations and training. There are 3 strings in the ground system. String 1 will be prime for real-time operations. String 2 will be prime for simulations and trending. String 3 will be prime for mission planning and be the hot back-up for real-time. There is also a back-up control center in Building 14.
    - » TRMM also has adequate personnel to support real-time operations and training. There are 7 full-time day staff positions (1 management, 5 engineers, 1 mission planner) and 8 real-time, spacecraft analysts on console (2 per shift).

15 Requests For Action

- RFA #12—Human Life
  - TRMM Project investigate and task some external group to do this analysis. The results must be documented. Need to validate the hypothetical lives saved number and examine TRMM historical data for any actual life savings that may have occurred (e.g. TRMM data allowed a flood warning to go out early enough to successfully evacuate an area during topical storm XYZ, etc.)
- Response—Open
  - In June 2001 a TRMM Risk/Benefit Workshop was held in Boulder, CO with an independent panel headed by Prof. Roger Pielke, Jr. (U. of Colorado). Most, but not all, of the panel subjectively estimated that the risk to human life of an uncontrolled reentry would be exceeded by the risk to human life of not having TRMM data for operational uses. This and other conclusions discussed in the Workshop report were reiterated in the September 2002 Code Q report on TRMM disposal risk considerations. No further effort has been made to obtain independent, quantitative estimates of TRMM's operational impact on "saving lives".

15 Requests For Action

- RFA #13—"Needs" vs. Requirements
  - Identify requirements for controlled re-entry vs. "needs". Make it clear which failures are triggers for start of controlled re-entry vs. anomaly investigation/evaluation.
- Response—Recommend closure.
  - There are currently no failures which are automatic triggers for the start of controlled re-entry. All failures will initiate an anomaly investigation.
    - » Details are provided in this review as well as section 3.5 of the TRMM Controlled Re-Entry Plan. Currently, for every component required for controlled re-entry, there is either a redundant component available, a work-around that restores redundancy, or the component is a single point failure the spacecraft launched with and is very unlikely to fail, at this point in the mission.
    - » Since this controlled re-entry plan is NOT conducted from mission altitude, controlled re-entry can NOT be initiated immediately in the event of a failure. The spacecraft altitude has to be lowered from 402.5km to 320km before the first re-entry delta-V burn can be performed. If rapid re-entry is desired, the required fuel to lower the orbit from 402.5km to 320km is 25kg.
  - Each component on the TRMM spacecraft has been evaluated to determine (1) whether it's required for controlled re-entry, (2) if redundancy exists in the event of a failure, and (3) whether any work-arounds exist to mitigate risk. The Table in the Appendix summarizes the results of this analysis. For each component required for controlled re-entry, a trigger level is assigned depending on the criticality of the component.

15 Requests For Action

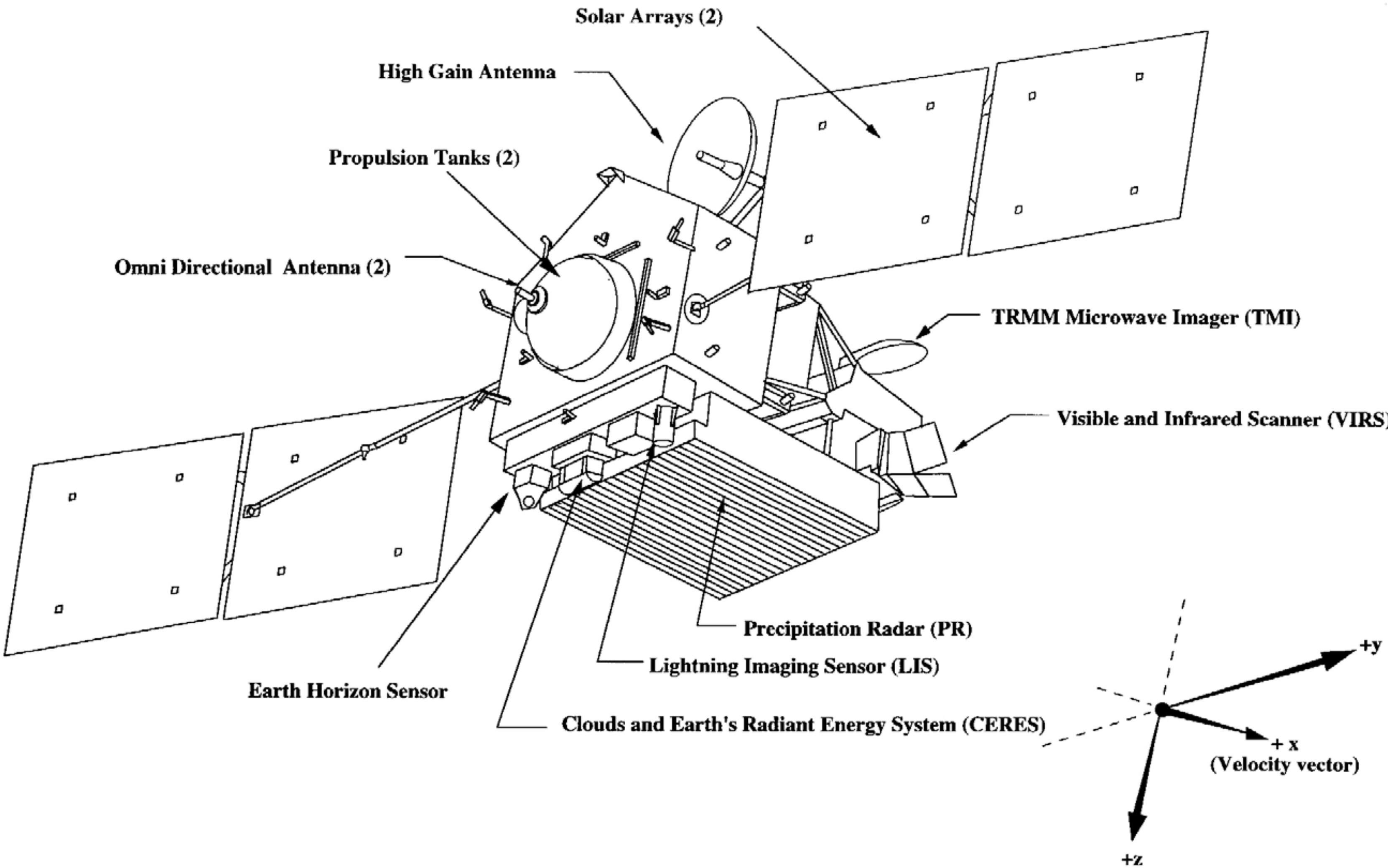
- RFA #14—Power
  - If a failure within the processor causes the processor to draw more current without causing the processor to stop, the bus voltage would look artifically low. Consider this failure mode. Perhaps monitoring several other points or switching to the other processor can reduce the risk of this failure mode.
- Response—Open; Flight Software CCR-101 "Spacecraft Processor B Current TSM" is open and being worked.
  - The existing TSM#42 monitors the filtered Spacecraft Processor A current draw. This provides a means to monitor a derived value of the essential bus voltage if the PSIB should have additional failures that cause the loss of the EBV telemetry. However, a failure of the Spacecraft Processor A would make an alternative source necessary. The CCR is to create a second TSM to monitor the Spacecraft Processor B current.
  - We need to work out the details of what the procedure would be to monitor processor B or switchover to processor B in the event processor A monitor looked strange but processor A was working This has been a lower priority CCR since it requires 2 failures to get to this condition and there is no way to test the monitor since processor B is powered off.

15 Requests For Action

- RFA #15—Operations
  - Consider establishing a standing anomaly review team to be on-call from this point forward. The team must understand that the project needs to know their whereabouts (or the whereabouts of their delegate) so they can be summoned at a moments notice.
- Response—Recommend closure.
  - TRMM has a clearly defined on-call list, escalation procedure, and subsystem points of contact in the event of an anomaly.
  - The formation of an anomaly review team is typically highly dependent upon the specifics of the anomaly.
  - Response to anomalies has been nearly immediate. We typically have an initial assessment within 24 hours of the first indication of a problem.

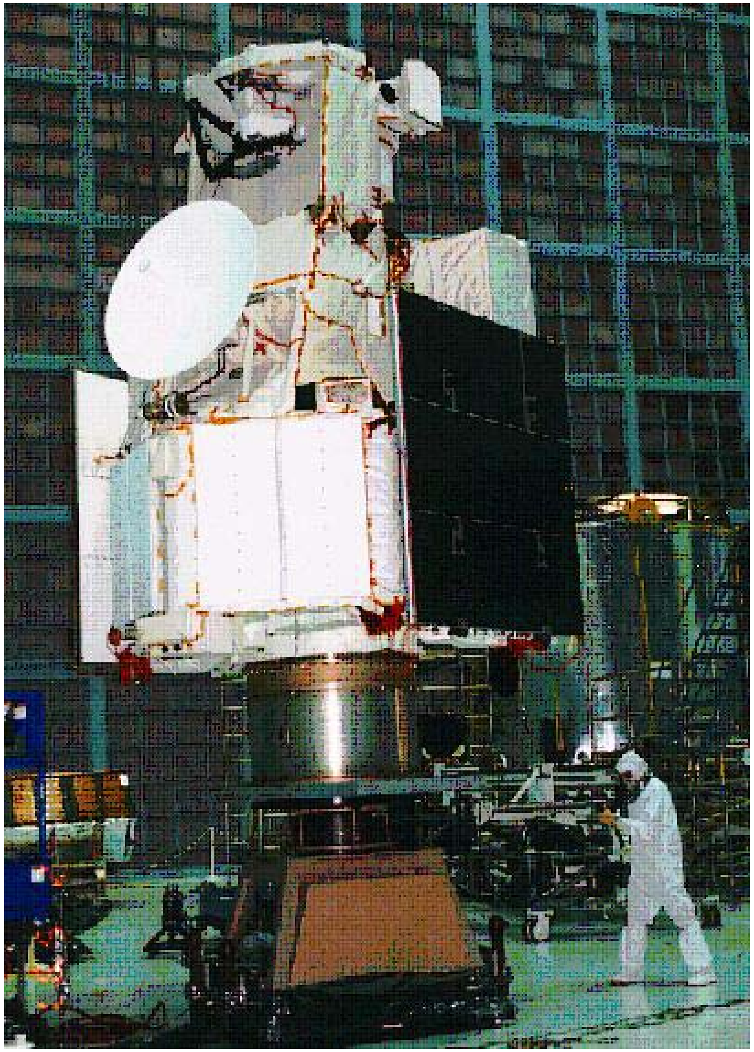
Spacecraft Overview & Status

TRMM Observatory
+Y SA Wing Indexed At +90°; -Y SA Wing Indexed At -90°



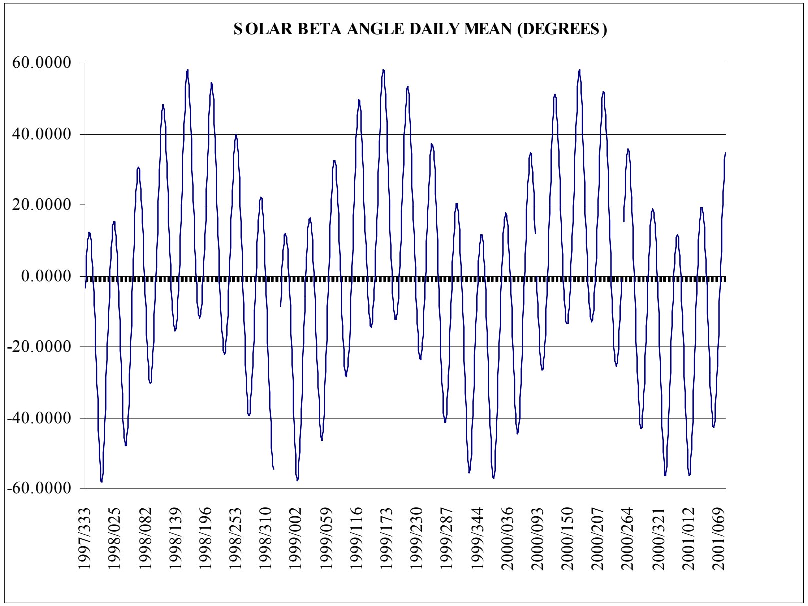
TRMM Systems Overview

- TRMM was the largest observatory built in-house at GSFC.
  - Size: 16.7 ft. long, 12.1 ft. diameter, 47.9 ft. across solar array
  - Mass:
    - » Dry Mass: 5766lbs (2621kg)
    - » Fuel Mass: 1962lbs (890kg)
    - » Total Launch Mass: 7728lbs (3512kg)
  - Power: Designed for 1100W orbital average (3.0kW peak). Actual load is 720W-780W.
- Class B spacecraft with redundancy where needed.
- Most hardware on TRMM had heritage from other projects such has SAMPEX and GRO. However, some hardware was “State of the Art”
  - Solid State Recorders
  - Fiber Optic Data Bus
  - Super NiCd™ Batteries
  - GaAs Solar Array
- Other technical “risk” areas were:
  - Atomic Oxygen



TRMM Systems Overview

- **TRMM was designed 3-axis stabilized, nadir-pointing for science.**
- **Orbital inclination of 35 deg yields a solar beta angle that varies from –58 deg to +58 deg wrt the orbit plane (XZ Plane).**
- **+/- X axis is velocity vector. +Z is nadir.**
- **Dual wing, deployed solar array is articulated about Y axis to track the sun in orbit plane.**
- **Maximum travel for the solar array is +/- 130 deg.**
- **Solar array panels are canted 26.5 deg to minimize the effect of the beta angle.**
- **Observatory performs a 180° yaw maneuver about once a month whenever the beta angle approaches 0 deg to keep the sun on the –Y side of the spacecraft.**
  - Besides optimizing power, there was a requirement to keep the sun off the VIRS instrument which was located on the +Y side of the observatory & having an anti-sun side facilitated the thermal design.



- **TRMM has a 91.5 minute orbit with a solar eclipse lasting 26-36 minutes each orbit.**
- **2, 50Ah Super NiCd™ batteries provide for the loads during the eclipse periods.**

TRMM Observatory Status

- **Anomalies Presented At April, 2001 Review—No Change In Status Of These**
  - **C&DH A Side Clock Card dropped out for 1.6 sec during the last simulation prior to launch. The B side clock card has been used since launch. A software patch can be used in the event of the failure of both clocks.**
  - **CERES instrument is off due to a failure of an internal power converter.**
  - **Battery 2 Cell 1 has anomalously high voltage at high charge rates. We are able to control this by limiting the charge rates used.**
  - **Selected power system telemetry has failed due to failure of one or more internal Interpoint power converters or shorts to output capacitors across the outputs of these converters.**

TRMM Mission Status

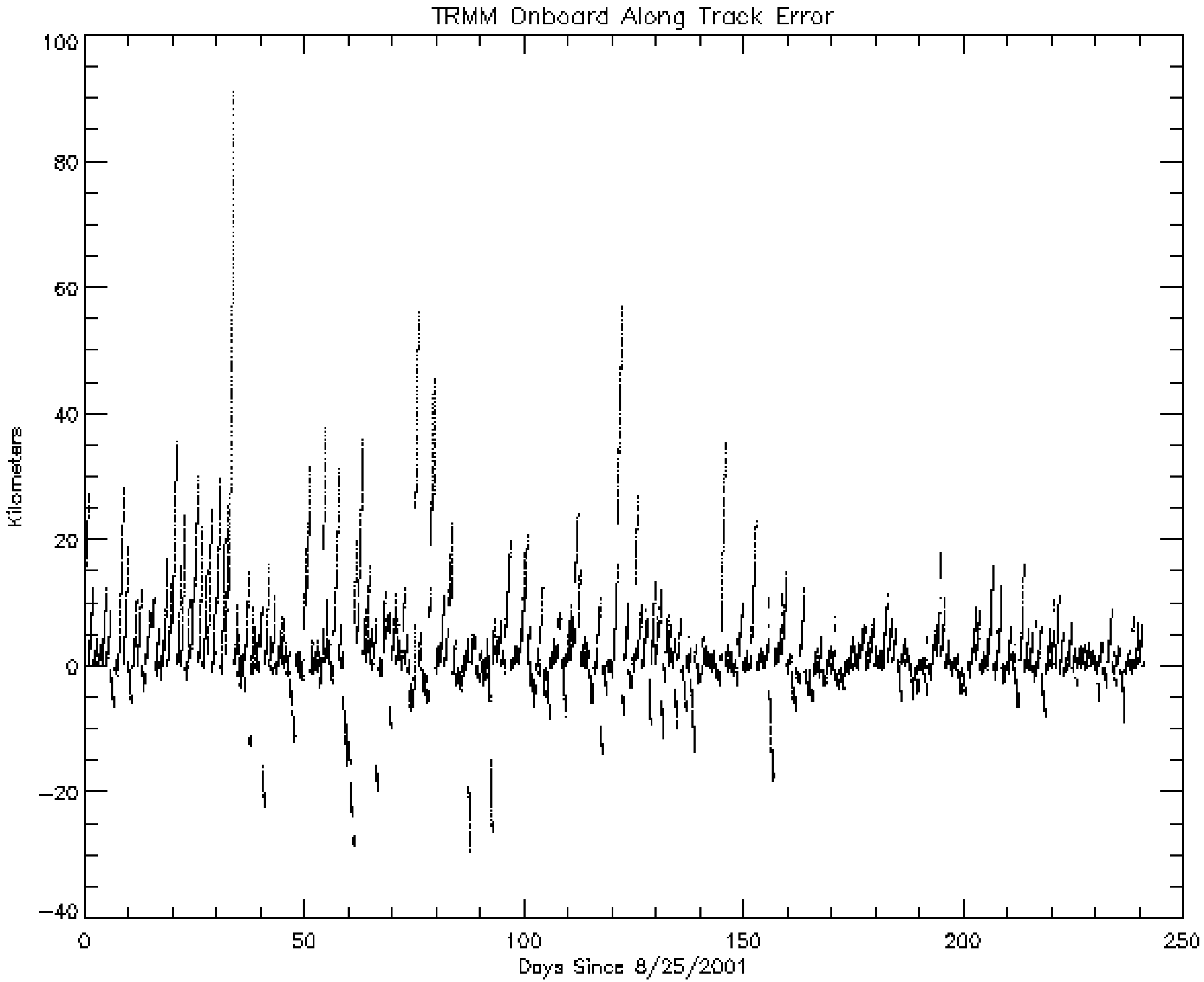
- TRMM just celebrated 5 years of science data collected (January 1998 to January 2003).
- There is still a strong desire, due to TRMM's improvement of storm analysis and forecasting, the climatic nature of the science, and the projected launch of a follow-on mission (GPM) in 2007 to extend the mission life as long as possible.
- The spacecraft and instruments are healthy. The limiting factor for the mission life is still the amount of hydrazine fuel remaining to maintain the low operational altitude.
- TRMM launched with 890kg of hydrazine and currently has 201kg remaining after the last delta-V maneuver (#425) on Jan. 19, 2003. Delta-V maneuvers are currently occurring presently every 7-12 days and consume about 1.1kg each.
- In August 2001, the operational orbit was raised from 350km $\pm$ 1.25km to 402.5km $\pm$ 1.0km to save fuel and extend the life.

New Anomalies Resulting From Orbit Boost

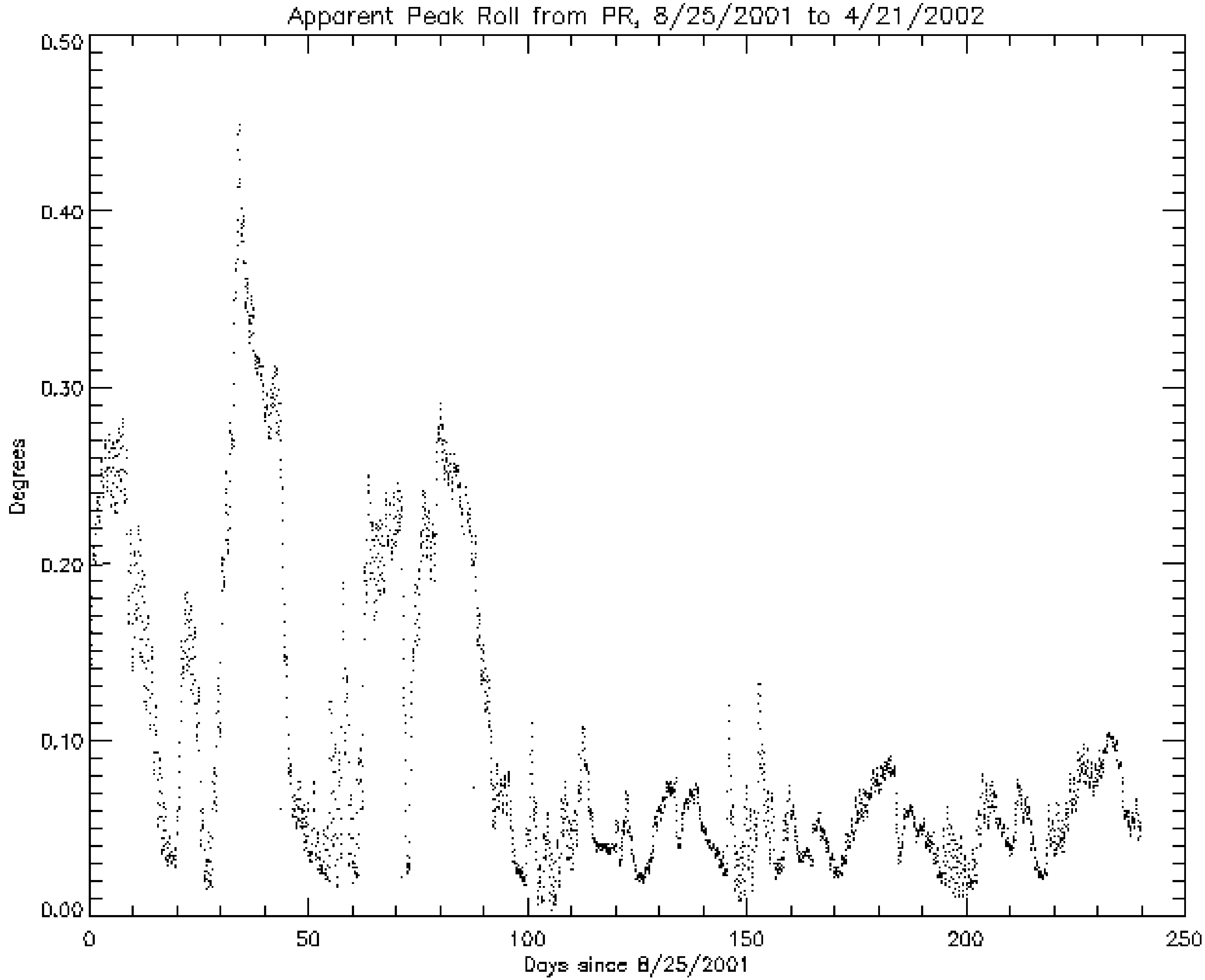
- Earth Sensor Failed At ~380km
  - Switched to Kalman Filter Contingency Mode
- TRMM experienced excursions in pointing accuracy outside specification after the switch to the Kalman filter. The problem was due to an ACS software error that has been corrected.

TRMM Pitch Error Since Orbit Boost

20km along track error roughly equivalent to .17deg



TRMM Roll Error Since Orbit Boost



Reducing The Solar Array Tracking To Save Fuel

- The TRMM solar array was designed for an 1100W load. The actual average load is 750-850W.
- Since launch, there have been discussions about feathering the array to reduce drag.
- This was not done because, in order to meet energy balance, with the solar array feathered, the battery charge parameters would have to be increased.
  - The maximum charge rate has to increase from 12A to 24A.
  - The temperature compensated voltage limit (V/T limit) has to be increased from 5 to 6.
- During the launch and early orbit phase, the batteries were charged with peak currents of 48A to V/T 5.
- Battery 2 Cell 1 peak voltage in charge slowly rose to about 1.55V about 60 days into the mission. This is considered dangerously high.
- The charge rate was dropped to 12A, V/T 5 (the minimum required for energy balance) and the battery 2 cell 1 voltage was maintained at 1.51-1.53V for the next 4 years.

Reducing The Solar Array Tracking To Save Fuel

- In addition, the –Y SADA temperature was higher than expected.
- About 6 months into the mission, it was also recommended that the array be feathered to eliminate the dependency on the SADA for the mission.
- In Feb. 1999, the software stops for solar array tracking were reduced from +/- 130 degrees to +/- 50 degrees.
- The 50 degree angle was selected as the maximum offset to allow 12A of charge into the battery at sunrise. It also reduced the duty cycle for the SADA in an attempt to extend the life.
- In addition, the software stops were set symmetrically to reduce the operational complexity of having to change the software stops after each yaw turn.
- The mission operated successfully in this way from ~Feb. 1999 to May 2002.
- In September 2000, the Power System Interface Box (PSIB) battery cell voltage telemetry failed on both sides. We have lost the direct measurement of the Battery 2 Cell 1 voltage. We are monitoring the battery voltage differential, which is the difference in voltage between the top 11 cells and the bottom 11 cells.

Reducing The Solar Array Tracking To Save Fuel

- With over 4 years of mission life accomplished and, assuming that controlled reentry would be required, the TRMM EOL team revisited the option of feathering the solar array to reduce drag and extend mission life.
  - Using March 2002 Schatten predictions, the TRMM lifetime projections were Oct. 2003 to April 2004 (under 2 years remaining).
  - There was no test data to show how the battery would respond to 24A, V/T 6. The only way to know if we could operate feathered was to try it, monitor battery performance and then make a recommendation.
- In May 2002, controlled testing of "feathering the solar array" was started.
- The solar arrays were feathered by setting the software stops to track the sun from –1 to +1 degree, building on the work that was done in 1999.
- 3 short duration (2 orbit) tests were run—May 30th, June 5th, and June 11th.
- These short tests were inconclusive at demonstrating energy balance or the effect of the higher charge rate on the battery differential.
- 2 longer duration tests were scheduled—June 24th to July 20th and Aug. 12th to Sept. 4th.
- The solar array was returned to tracking mode July 20-Aug. 12 because the beta angle was extremely low (below 15 degrees) and energy balance was uncertain. In addition, it was decided that the solar array drive should be exercised on a monthly basis.

New Anomaly: -Y SADA Sticking

- **On Sept. 4th, when switching from feathered to track mode, the –Y SADA stuck intermittently on 2 consecutive orbits.**
  - The –Y wing has been permanently stowed at 0 degrees (minimum drag) to prevent it from stopping in an unfavorable location.
  - The +Y wing remains tracking the sun –50 to +50 degrees.
    - » The +Y wing can not be stowed at 0 degrees to save fuel because we can not meet energy balance at 12A, VT 5
      - Charging at 24A, VT6 is required for all instruments to be on.
      - Charging at 24A rate raised the battery 2 voltage differential from 132mV to over 200mV (+68mV) using VT5 with LIS and VIRS off.
      - Cell voltage could be as high as 1.58-1.60V, which is over the gassing potential for the cell. Power branch recommends charging with a limit of 12A and preferably VT5.

Reducing The +Y Solar Array Tracking To Save Fuel

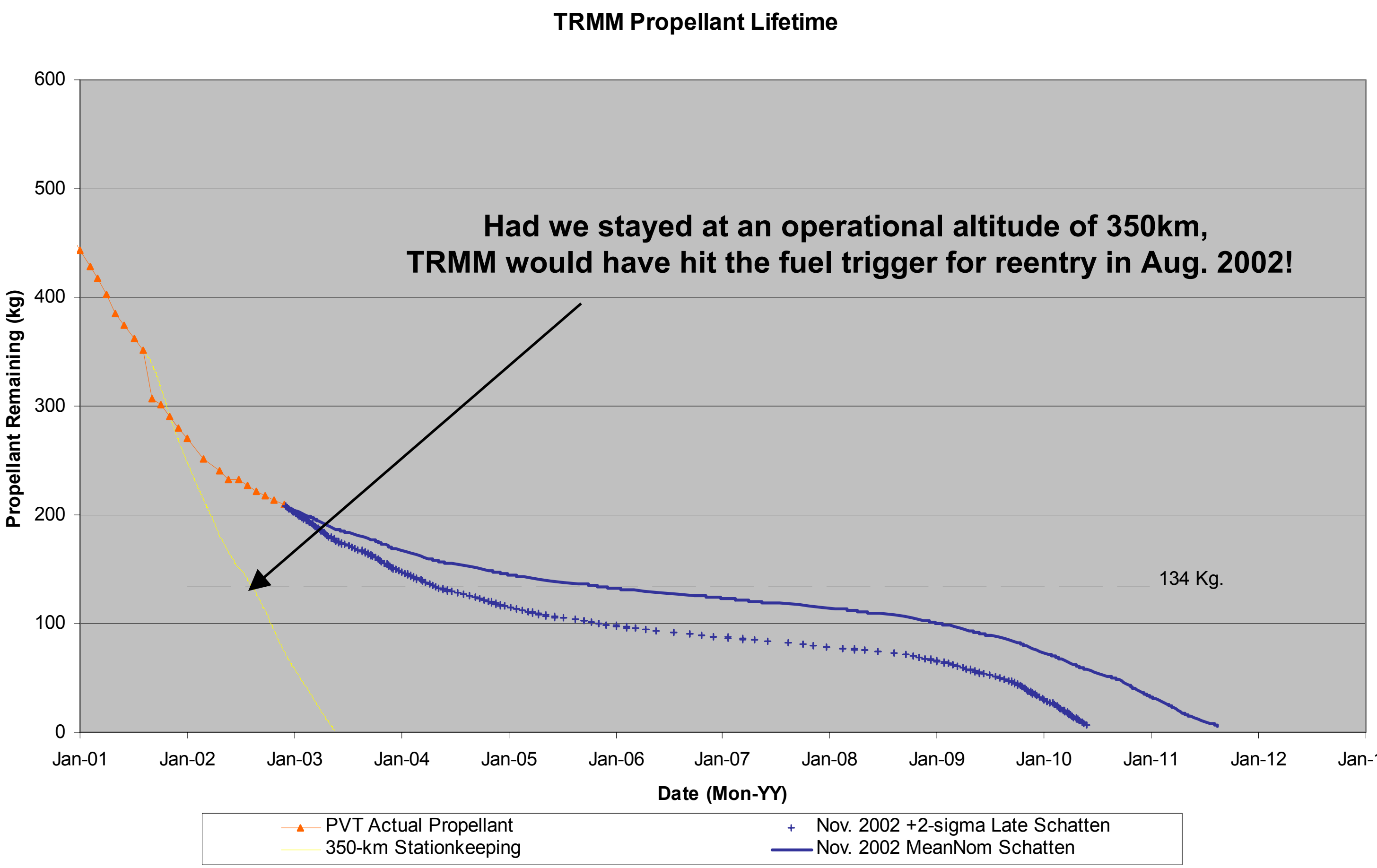
– Dec. 9 to Dec. 19, 2002 the tracking for the +Y wing was reduced from +/- 50 degrees to +50 to 0 degree. Energy balance could not be achieved without accepting additional mission risk—either increasing the charge parameters to battery 2 periodically or switching back and forth between track modes.

– It has been decided, with the concurrence of the Project Scientist, to continue to operate in the lowest risk mode (I.e. +Y wing tracking –50 to +50 degrees) and accept the additional drag.

TRMM Controlled Reentry Overview

- The current fuel budget for controlled re-entry is 134kg (15% total launch fuel).
- A final orbital debris analysis was completed in September 2002 showing the expected casualty area for TRMM is ~11.3 m^2. This is over the NSS guideline of 8m^2 indicating that TRMM may be required to perform the controlled & targeted reentry. No final decision on this has been made.
- Under the current plan for controlled reentry, once TRMM's fuel level reaches 134kg, sometime between April 2004 and November 2005, delta-V maneuvers would be terminated and the spacecraft would be allowed to decay from 402.5km to 320km. The decay would take 1.6-3.0 years. During this time, the current plan is to continue to take and process science data; however, this has not been approved by NASA HQ. The burns to force the spacecraft into the Pacific Ocean would commence from 320km and would take, nominally, 2 days.
- If TRMM were to use all of its hydrazine to maintain 402.5±1.0km for science, it would last at least 6 additional years (11+ years total), excluding any mission ending spacecraft failures, and when it ran out of fuel it would reenter the Earth's atmosphere.

TRMM's Lifetime Predictions



Re-Entry Decision Milestones

	+2 Sigma Solar Flux	Nominal Solar Flux
• Spacecraft reaches 134kg	**April 2004**	**November 2005**
• Decay Time (assuming +Y tracking ±50º, -Y stowed at 0°; 12.5m^2 drag area)	**1.6-1.8 years**	**2.8-3.0 years**
• Start Of Re-Entry Maneuvers	**Oct 2005-Jan 2006**	**July 2008-Sept 2008**

- Note: The decay time can be reduced slightly if the +Y wing tracking range is increased during the day and the +Y wing is stowed at ±90° during the night. (Best case of 17.0m^2 reduces decay time to 1 year (+2 sigma flux) to 2.2 years (nominal flux).

- 25kg of propellant is required to bring orbit down from 402.5km to 320km.

• Spacecraft reaches 159kg	**October 2003**	**April 2004**